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Socioeconomic inequalities explain the association between source of drinking water and dental caries in primary dentition

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ABSTRACT

Objective: To evaluate the association between source of drinking water and dental caries at age 5 and to test whether socioeconomic conditions act as confounding factors in such association.
Methods: The study was carried out in a sub-sample of the 2004 Pelotas Birth Cohort, which comprised the application of a questionnaire and clinical oral examination. The exposure was source of drinking water, collected through a question to the primary caregiver. The outcome was dental caries in primary dentition, measured through several standardized indicators of the decayed, missing and filled teeth index (dmft), assessing past and present dental caries. Socioeconomic indicators (family income and maternal education) were identified as potential confounding factors. After descriptive analysis, the association between source of water and measures of dental caries was assessed by Regression models.
Results: 1,084 children were evaluated and had complete information in all variables (83.2 % of the targeted sample). Dental caries experience was observed in 48.7 % of the children, with a mean of 1.9 decayed, missing or filled teeth. Most children consumed water from public water supply (76.0 %), and a socioeconomic pattern was observed, with children from lower income more likely to drink water from public supply. In crude analysis, children who consumed bottled water had a lower risk of decayed teeth, lower experience of dental caries and less severe disease. No associations were observed after adjustments for socioeconomic conditions.
Conclusion: Underlying socioeconomic inequalities explained the association between prevalence and severity of dental caries in primary dentition and source of drinking water.
Clinical significance: Drinking fluoridated tap water is as effective in dental caries prevention as bottled water with acceptable levels of fluoride, with the advantage of being accessible to all. Oral health prevention and treatment should be implemented as early in life as possible and should take into consideration the family's socioeconomic context.

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1. Introduction

Dental caries is a public health problem, and its health and economic burden is a serious concerns for individuals and communities [1]. In primary teeth, evidence on untreated dental caries indicate a stable global age-standardized prevalence of 9.0 % between 1990 and 2010, with a decrease to 7.8 % in 2015 [2]. Data from the last Brazilian national oral health survey conducted in 2010 [3] showed that five-year-old children presented a mean Decayed, Missing and Filled Teeth Index (dmft) of 2.4, with the decay component accounting for more than 80 % of the index. Also, children dental care is frequently neglected, especially within public health service [4]. The inadequate access to and prohibitive cost of dental caries treatments may lead to several consequences, especially among those from low socioeconomic backgrounds [5]. Tooth decay is the main cause of dental pain in childhood, which may unfavorably affect the children's and parents' quality of life [6]. Furthermore, it may affect the child's ability of eating, speaking, and sleeping, which may impair the child's development and wellbeing, and impact school performance [5].

Oral diseases, and specifically dental caries, are not evenly distributed in the population. It is well documented that socioeconomically disadvantaged people suffer from an unfairly bigger share of these problems. Systematic reviews within the Brazilian context [7] and worldwide [8] concluded that people experiencing socioeconomic disadvantage were at a higher risk of presenting dental caries, and the association was consistent for several socioeconomic indicators. Also, socioeconomic inequalities early in life may have a long-lasting effect on systemic and oral health, with its oral health consequences observed until adulthood [9].

One of the most effective methods for caries prevention is the use of fluoride ions to reduce the demineralization and increase the remineralization process [10]. Indeed, public water fluoridation is considered the most relevant public policy on oral diseases prevention, as well as one of the 10 most important public health policies in the 20th century in the USA [11]. Furthermore, the addition of fluoride in the water from public supply is considered a low cost method, with a low impact in government budgets [12].

Although water fluoridation is still widely recognized as effective to prevent dental caries, a systematic review with a restrict study selection criteria highlighted that there is insufficient evidence to determine whether water fluoridation results in a change in disparities in caries levels across SEP [13]. The same study pointed out the need for more contemporary studies assessing the effect of water fluoridation on dental caries.

On the other hand, regardless of the preventive effect of drinking public fluoridated water on dental caries, Brazil is facing a trend of increased consumption of bottled water, instead of the consumption from public water supply [14]. This change has been related, among other factors, to doubts in relation to the suitability of tap water for drinking [15]. Since the costs associated with drinking bottled water is prohibitive to many families, this trend has been socially patterned, with poorer families relying on publicly available tap water, while richer families can afford bottled water [16]. Additionally, the consumption of bottle water, if fluoride levels are not optimal, may increase the risk of dental caries.

To summarize, individuals from more vulnerable socioeconomic contexts bear a higher burden of dental caries [8]. Public water fluoridation may be an effective, safe, and socioeconomically fair public health measure to reduce dental caries [17]. On the other hand, it has been observed an increase of bottled water consumption among better off families [14], and this consumption may increase the risk of dental caries and its outcomes. Additionally, an association between source of water consumption and dental caries may be biased by socioeconomic position, since this social pattern of water source result on those from a higher socioeconomic background, which have a lower risk of the outcome (dental caries), also being less exposed to a potentially preventive measure (consumption of tap water).

Considering the need for contemporary evidence on the association between water and dental caries and the increase in bottled water consumption in Brazil, it is appropriate to evaluate whether this trend would impact the risk for dental caries in children. It is equally important to evaluate the role of socioeconomic position on such an association. Thus, the present study aimed to evaluate the association between source of water consumption and dental caries experience at age 5 in a birth cohort in Pelotas, Southern Brazil, and to test whether this association is stable after adjustments for socioeconomic conditions.

2. Methods

In 2004, 4,558 children were born in the urban area of Pelotas, South Brazil, and in Jardim America, a district from the city of Capão do Leão, a contiguous neighbor city of Pelotas. Of the 4,231 live births, 99 % were evaluated within the first 24 h after birth, 96 % at 3 months of age, and 94 % followed-up at 12 months of age. Information about the methodology of the 2004 Pelotas Cohort Study is available elsewhere [18].

This research is part of an oral health survey carried out between August and December 2009, nested on the 2004 Pelotas Birth Cohort. The mothers of all 5-year-old children born between August and December 2004 who were visited when they were 12-month-old (n = 1,303) were invited to participate. This sample size is suitable to estimate rates of 50 % for oral outcomes, with a sampling error of three percentage points. Moreover, the sample size is large enough to test associations with a power of at least 80 % to identify significant relative risks of 2 or more, considering a prevalence of 5% of outcomes among not exposed and adopting a significance level of 5%.

The oral health survey comprised a questionnaire applied to the mother and an oral examination of the child, both performed at their homes. For the data collection, dentists, assisted by undergraduate dental students, conducted the interviews and the oral examinations. This sequence was followed to ensure that questionnaire responses were not influenced by the clinical outcomes.

Eight dentists, Masters or PhD students at the Federal University of Pelotas, conducted the oral examinations. Prior to the data collection, the research team was trained and calibrated. For the calibration process, which was performed at schools, 100 preschoolers of the same age who were not part of the study were examined. Intra-examiner reliability measure for dental caries (dmf-s) ranged between 0.93 and 1.0 (intraclass correlation coefficient). Examiners used headlight, dental mirror and World Health Organization (WHO) periodontal probe. Dental examination was performed following the WHO biosafety recommendations for epidemiologic surveys. To evaluate data quality, 15 % of interviews were repeated with a reduced version of the questionnaire by the study coordinators.

This study was approved by the Ethics Committee of the Federal

University of Pelotas (#100/2009). All examinations and interviews were carried out after parents or guardians signed a consent letter. Children who had dental needs were referred to the Pediatrics Dental Clinic, Dental School, Federal University of Pelotas.

Exposure: The exposure was source of drinking water, as a proxy for fluoride exposure. This variable was collected through a single question, asked to the mother: "What is the source of the water the child uses to drink, to prepare juices and teas?". Possible answers were: "tap water", "filtered water", "bottled water", "well water", "other", "the child doesn't drink any water", and "I prefer not to answer it". For analytical purposes, the variable was dichotomized into "tap/filtered water" (0) and "bottled water" (1). For children that drank more than one source of water, mothers were instructed to answer with the source of water the children drank the most. Children who were reported to drink water from sources other than tap/filtered water and bottled water were excluded from the analysis (15 children).

Outcome: The outcome was dental caries in primary dentition, measured through the Decayed, Missing and Filled Teeth Index (dmft index) when participants were 5 years old [19]. The dmft index captures an individual's cumulative experience of past and present dental caries, whether untreated (the number of decayed teeth) or treated (filled teeth or missing teeth extracted because of caries). Several variations of the outcome were assessed: the complete, continuous index, each of its components (decayed, missing and filled teeth), and the presence of any experience of dental caries. We also evaluated the severity of the problem by means of tertiles of the dmft index. The first tertile of the dmft index presented no experience of dental caries, while the second tertile had 1 or 2 teeth affected by dental caries and children in the third tertile had 3 or more decayed, missing or filled teeth.

Confounding factors: Socioeconomic indicators were potential confounding factors of the relationship between source of water and dental caries, since both exposure and outcome are socially patterned. The socioeconomic indicators assessed were maternal education and family income, both collected through interview at the child's birth. Family income referred to the total amount of household earnings in the month before birth. Maternal education was collected in number of years of formal education completed. Both variables were included in the analyses as they were measured (continuous/discrete variables).

2.1. Statistical analysis

Statistical analysis was conducted in Stata 15.0. Descriptive analysis was carried out to evaluate absolute and relative frequencies of covariates by the presence of dental caries. The association between source of water and measures of dental caries were assessed by regression analysis, estimating prevalence ratios and 95 % confidence intervals (95 % CI). For the continuous outcome (i. e. dmft index), negative binomial regressions were used. Poisson regressions with a logarithm link function were applied for binary outcomes. Finally, multinomial logistic regressions were used to assess the association between source of water and severity of dental caries. All regression models were fit with robust variance estimates. Sensitivity analysis for unmeasured confounding was conducted and E-values were assessed. This approach [20] evaluates how strong the association of a confounding factor with both exposure and outcome, conditional on the measured covariates, would need to be in order to change or eliminate the observed effect of the exposure on outcome. The relationship between the variables is presented in a Directed Acyclic Graph (Supplementary Fig. 1).

Table 1
Distribution of outcome variables. 2004 Pelotas Birth Cohort Study. n = 1,084.

Number of decayed teeth	
Mean	1.8
Median	0
% > 0	46.0%
Number of missing teeth	
Mean	0.01
Median	0
% > 0	0.9%
Number of filled teeth	
Mean	0.1
Median	0
% > 0	5.5%
Number of decayed, missing and filled teeth	
Mean	1.9
Median	0
% > 0	48.7 %

Table 2
Descriptive analysis and association of caries prevalence at age 5 with socioeconomic, demographic, and behavioral variables. 2004 Pelotas Birth Cohort Study. Row percentages. n = 1,084.

Variable/Category	Dental caries, n (%)		P value
	Absent	Present	
Gender			0.039
Male	278 (48.3)	297 (51.7)	
Female	278 (54.6)	231 (45.4)	
Maternal schooling, years			<0.001
≤4	56 (40.0)	84 (60.0)	
5–8	196 (45.0)	240 (55.0)	
9–11	221 (57.3)	165 (42.7)	
≥12	83 (68.0)	39 (32.0)	
Familial income			<0.001
1 st quintile	105 (40.9)	152 (59.1)	
2nd quintile	87 (46.8)	99 (53.2)	
3rd quintile	129 (50.0)	129 (50.0)	
4th quintile	107 (58.8)	75 (41.2)	
5th quintile (richest)	128 (63.7)	73 (36.3)	
Source of drinking water			0.002
Tap	401 (48.7)	423 (51.3)	
Bottled	155 (59.6)	105 (40.4)	
Total	**556 (51.3)**	**528 (48.7)**	

3. Results

The response rate was 86.6 % (n = 1,129). However, data on dental caries were collected from 1,123 children because six children refused examination. Additionally, 39 children had missing data in other variables of interest. All analyses pertain to the 1,084 children with complete information on all variables (83.2 % of the targeted sample). Sociodemographic characteristics of the complete cases are similar to the 2004 Pelotas Birth Cohort Study baseline (data not shown). Dental caries experience was observed in 48.7 % of the children (n = 528), with a mean of 1.9 decayed, missing or filled teeth. Untreated dental caries accounted for the largest share of the dmft index (Table 1). In relation to the type of water, 76.0 % of the children consumed water from public water supply (59.4 % tap water and 16.6 % filtered tap water) and 24 % consumed bottled water. In the bivariate analysis, all covariates were associated with dental caries (Table 2). Among children who presented dental caries, 80.1 % of them were reported to consume tap water, compared to 72.1 % among children who did not present dental caries.

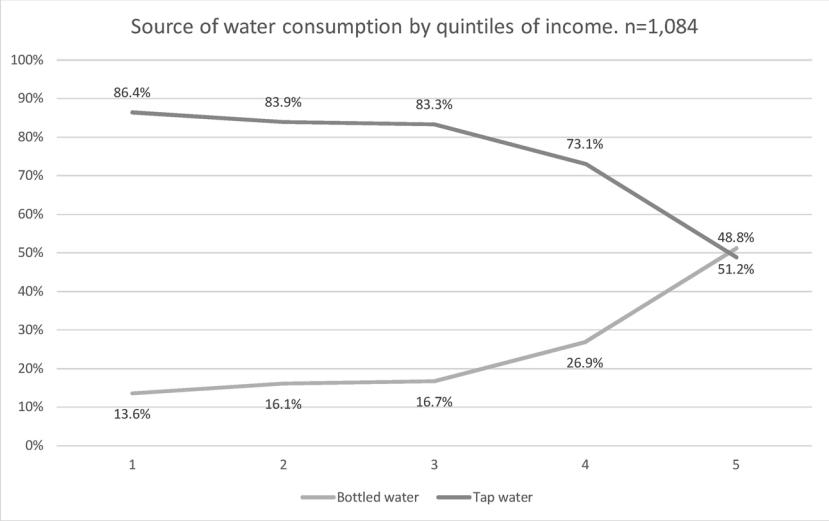

Fig. 1. Source of drinking water according to family income in children aged 5, Pelotas 2004 Birth Cohort (n = 1,084). Pelotas 2009.

Table 3
Crude and adjusted analysis of the association between source of drinking water and several measures of dental caries. 2004 Pelotas Birth Cohort Study. n = 1,084.

	Crude analysis		Adjusted analysis*	
	PR (95 % CI)	E-value	PR (95 % CI)	E-value
Source of drinking water	Number of decayed teeth (D-T)			
Tap	–		–	
Bottled	0.53 (0.41; 0.67)	3.18	0.82 (0.63; 1.07)	1.74
Source of drinking water	Number of missing teeth (M-T)			
Tap	–		–	
Bottled	1.06 (0.27; 4.16)	1.31	3.28 (0.99; 10.85)	6.01
Source of drinking water	Number of filled teeth (F-T)			
Tap	–		–	
Bottled	2.44 (1.27; 4.71)	4.31	1.47 (0.82; 2.66)	2.30
Source of drinking water	Number of teeth with dental caries experience (DMFT)			
Tap	–		–	
Bottled	0.61 (0.48; 0.77)	2.66	0.85 (0.67; 1.09)	1.63
Source of drinking water	Any dental caries experience (DMFT binary - 0 versus 1+ teeth)			
Tap	–		–	
Bottled	0.79 (0.67; 0.93)	1.85	0.99 (0.83; 1.17)	1.11

* All analyses adjusted for maternal education and family income.

Table 4
Crude and adjusted analysis of the association between source of drinking water and dental caries severity. 2004 Pelotas Birth Cohort Study. n=1,084.

	Crude analysis			
	PR (95% CI)	E-value	PR (95% CI)	E-value
	DMFT 2nd tertile (1-2 teeth decayed, missing or filled)		DMFT 3rd tertile (3+ teeth decayed, missing or filled)	
Source of drinking water				
Tap	-		-	
Bottled	0.85 (0.59; 1.22)	1.63	0.51 (0.36; 0.73)	3.33
	Adjusted analysis*			
	PR (95% CI)	E-value	PR (95% CI)	E-value
	DMFT 2nd tertile (1-2 teeth decayed, missing or filled)		DMFT 3rd tertile (3+ teeth decayed, missing or filled)	
Source of drinking water				
Tap	-		-	
Bottled	1.07 (0.73; 1.59)	1.34	0.81 (0.55; 1.19)	1.77

Reference category: DMFT 1st tertile.
* Adjusted for maternal education and family income.

When analyzing the source of drinking water and the family socioeconomic level, most of the children from lower income consumed water from public supply, while in the richest quintile bottled water was mostly consumed (Fig. 1).

Crude and adjusted analyses for the association between source of drinking water and dental caries are presented in Table 3. In crude analysis, children who were reported to consume bottled water had a lower risk of decayed teeth, a lower dmft index, and a smaller prevalence of presenting any experience of dental caries (dmft>0). For example, children who consumed bottled water had a lower risk of presenting dental caries experience than those who used to drink tap water (PR = 0.61; 95 % CI 0.48; 0.77), E-value 2.66. Different results were observed for the components of the dmft index related to dental treatment: filled teeth and missing teeth due to caries. When the presence of filled teeth was the outcome, children who consumed bottled water were at a higher risk of presenting the outcome (PR 2.44; 95 %CI 1.27; 4.71), E-value 4.31. Analyses for the association between source of drinking water and missing teeth yielded no association. After adjustments for family income and maternal education, no associations between source of drinking water and dental caries were observed.

Table 4 presents the association between water source and severity of dental caries. In crude analysis, drinking bottled water was associated with a lower risk of more severe dental caries experience (3rd tertile of dmft index). The inclusion of socioeconomic indicators into the models seems to have explained the previously observed relationship, since no associations were observed after socioeconomic indicators were taken into account.

4. Discussion

This study identified the clear role of socioeconomic position as a confounding factor in the association between source of consumed water and dental caries. Even though children who were reported to drink bottled water had lower levels of dental caries, the findings of our study show that family income and maternal education explained the association between source of drinking water and the prevalence or the severity of caries in children aged 5 in the 2004 Pelotas Birth Cohort.

The strengths of this study include the longitudinal nature of the data collection, with confounding factors collected at the child's birth, reducing the likelihood of information bias, and the high consistency of the results identified in our analyses. The sensitivity analysis suggested that, for an unmeasured confounding to explain away the observed association, it would need to have a strong association with both source of drinking water and dental caries. To the best of authors' knowledge, the only group of confounding factors that could have such an effect in the source of water-dental caries association would be socioeconomic factors, but all analyses were already adjusted for maternal education and family income. Therefore, we do not believe there are unmeasured characteristics that could explain away our findings. Also, dental caries was clinically evaluated by a trained and calibrated team. The large sample size is another positive aspect of this study. Additionally, prior knowledge of the water supply-dental caries relationship and the role of socioeconomic position allowed us to identify the confounding bias with a relatively straightforward analysis. The subject knowledge guided our analysis and avoided the dissemination of the wrong information that tap water is causally associated with dental caries.

The present study is not free of limitations. The main limitation is that both exposure and outcome were collected at the same time. Additionally, the source of water consumption was based on a single question, to capture the source of water the child drinks the most. However, this approach may lead to information bias since children may or may not consume only one type of water. Also, parents may report what they understand to be the socially desirable, and this could lead to information bias. Another potential source of bias is related to the stability in the fluoridation status of the tap water children were consuming. However, in 2009 a study was conducted to evaluate the 12-month stability of fluoride levels in tap water in Pelotas. Data collection took place monthly in 16 geographically distributed places in the city. The results pointed out that 15 areas (93 %) were classified as presenting optimal fluoride concentration [21]. Additionally, the City Sanitation Agency's website (SANEP) [22] presents annual reports on the quality of tap water. It is currently possible to access reports from 2008 to 2019. According to the reports, the mean concentration of fluoride in tap water in Pelotas for all the years evaluated was within acceptable levels according to the Brazilian Ministry of Health, which recommends levels between 0.6 to 0.9 mg/L. Our findings confirm that the publicly available water in Pelotas presents adequate and stable levels of fluoride and rejects the hypothesis that the increased levels of dental caries among those drinking tap water is related to the lack of water fluoridation.

Findings from crude analysis showed different directions of association. While outcomes related to dental caries experience and untreated dental caries showed a protective effect of bottled water, outcomes that measured disease treatment, i.e. filled and missing teeth, were more prevalent among bottled water drinkers. This may reflect the socioeconomic pattern of consumption of bottled water: those socioeconomically advantaged families, who can afford bottled water, are also those who have access to dental treatment. This corroborates with a systematic review on children's dental attendance, which showed that parents' education and socioeconomic status are some of the barriers of parents' adherence to regular dental attendance for their children [23].

The confounding effect of socioeconomic position in the association between source of drinking water and dental caries is well-defined in our findings. The inclusion of two socioeconomic indicators totally explained the association. These indicators of socioeconomic position may reflect a broad range of contextual and individual conditions. For example, family income and maternal education may reflect the neighbourhood where the family lives, the type of school attended, their level of health literacy, health service utilization frequency and pattern, and behaviours, such as diet and oral hygiene. These are some of the pathways through which socioeconomic conditions may affect dental caries [8]. In our study, when socioeconomic conditions were considered, the association between water source and dental caries was no longer observed, meaning that socioeconomic differences were behind the disparities in dental caries for children who consume tap water and bottled water. It is very plausible that socioeconomic position would have such a role, since it is a common cause of both dental caries and tap water consumption. This explanation is corroborated by previous studies that show that socioeconomic position is a determinant of oral health in children [9]. Children from lower income families or children whose mothers present lower educational levels have less access to regular and preventive dental services, and less access to information about health habits and have more cariogenic diets [24].

Our findings may be erroneously interpreted as challenging public water fluoridation, since the lack of an association between source of drinking water and dental caries may imply that drinking tap water has no effect on caries prevention, compared to bottled water. However, several studies have been conducted evaluating the level of fluoride in Brazilian bottled water. Some of them have reported that levels of fluoride would be below or sometimes above of the recommended for caries prevention [25,26]. Importantly, a study carried out in Pelotas with the bottled brands available in the market when this study was conducted showed that most of the bottled water presented an acceptable level of fluoride for caries prevention [21]. On the other hand, a study published in 2005 also evaluating fluoride content in bottled water in Pelotas reported heterogeneous values, with fluoride levels ranging from 0.04 to 3.13 ppm [26]. It is important to consider that individuals who drink bottled water will probably also ingest water from public supply when preparing their food and will also have contact with fluoride from the toothpaste. Even if bottled water did not have acceptable fluoride levels, which evidence suggests was not the case in Pelotas when the present study was conducted, fluoride from the tap water used in food preparation and from the toothpaste would be sufficient enough to prevent dental caries [27]. In fact, more than 90 % of the evaluated children had their teeth brushed at least twice a day (data not shown). In Brazil, almost all toothpastes have fluoride in their composition [10,28].

Our findings reinforce the importance of maintaining optimal levels of fluoride in public water, since water fluoridation is, undeniably, a safe and effective public health measure to prevent dental caries. Bottled water is unaffordable to many families, and our study showed that, even though it was conducted in a context where bottled water in general present an acceptable level of fluoride, no differences were observed in the levels of dental caries after socioeconomic conditions were considered. Showing that the consumption of tap water is not independently associated with dental caries represents that it is as healthy as bottled water with an acceptable level of fluoride in preventing dental caries, with the advantage of being accessible to all.

Nowadays, even with supplies of clean water to every home in big cities, most people in low and middle income countries prefer to consume bottled water, either from local companies or imported [29]. While we believe the findings of this study can be generalized to other contexts, one should be careful to consider the quality of both bottled and tap water when applying these results. In a context where both bottled and tap water appear to have adequate levels of fluoride, such as Pelotas, one can carefully expect that any differences in dental caries prevalence may be explained by socioeconomic inequalities.

In conclusion, the association between source of drinking water and dental caries was observed only in crude analyses. Underlying socioeconomic inequalities explained the association between prevalence and severity of dental caries in primary dentition and source of drinking

water. It is important to recognize that prevention and treatment in oral health should be implemented as early in life as possible. Such approach should take into consideration not only the children but also the family context in which they live.

CRediT authorship contribution statement

Helena Silveira Schuch: Conceptualization, Formal analysis, Writing - original draft. **Raquel Venâncio Fernandes Dantas:** Conceptualization, Writing - original draft. **Lenise Menezes Seerig:** Conceptualization, Formal analysis, Writing - review & editing. **Iná S. Santos:** Methodology, Investigation, Resources, Writing - review & editing, Project administration, Funding acquisition. **Alícia Matijasevich:** Methodology, Investigation, Resources, Writing - review & editing, Project administration, Funding acquisition. **Aluísio J.D. Barros:** Methodology, Investigation, Resources, Writing - review & editing, Project administration, Funding acquisition. **Karen Glazer Peres:** Methodology, Investigation, Resources, Writing - review & editing. **Marco Aurélio Peres:** Methodology, Investigation, Resources, Writing - review & editing. **Flávio Fernando Demarco:** Conceptualization, Methodology, Investigation, Resources, Writing - review & editing, Supervision, Project administration, Funding acquisition.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Appendix A. Supplementary data

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